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The John Insall Award

Both Morphotype and Gender Influence the Shape of the Knee in Patients Undergoing TKA

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Abstract There is an ongoing debate whether gender differences in the dimensions of the knee should influence the design of TKA components. We hypothesized that not only gender but also the patient's morphotype determined the shape of the distal femur and proximal tibia and that this factor should be taken into account when designing gender-specific TKA implants. We reviewed all 1000 European white patients undergoing TKA between April 2003 and June 2007 and stratified each into one of three groups based on their anatomic constitution: endomorph, ectomorph, or mesomorph. Of the 250 smallest knees, 98% were female, whereas 81% of the 250 largest knees were male. In the group with intermediate-sized knees, female knees were narrower than male knees. Patients with smaller knees (predominantly female) demonstrated large variability between narrow and wide mediolateral dimensions irrespective of gender. The same was true for larger knees (predominantly male). This variability within gender could partially be explained by morphotypic variation. Patients with short and wide morphotype (endomorph) had, irrespective of gender, wider knees, whereas patients with long and narrow morphotype (ectomorph) had narrower knees. The shape of the knee is therefore not only dependent on gender, but also on the morphotype of the patient.

Level of Evidence: Level I, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Introduction

Gender-specific knee implants have recently become available based on the observation that differences exist in the shape of the knee between men and women. Data from the literature suggest that for any given anteroposterior femoral dimension, women tend to have more narrow mediolateral dimensions than men [7, 14, 17, 20, 21]. The use of standard implants could, therefore, in theory, lead to mediolateral overhang in women, causing irritation and pain of the soft tissue capsular envelope of the knee.

The question remains, however, how valid this concept is in the patient population undergoing TKA and whether gender-specific components should become standard in use. The patient population undergoing TKA is indeed predominantly female and may therefore not necessarily require female and male versions of all components, especially for the smaller sizes. A female version with smaller sizes and a more male version with larger sizes could, for example, be a less expensive and less inventory-requiring solution than providing male and female versions for all sizes.

Apart from gender, other factors seem to influence the geometry of the knee as well. Within gender, there is indeed a considerable variability in distal femoral and

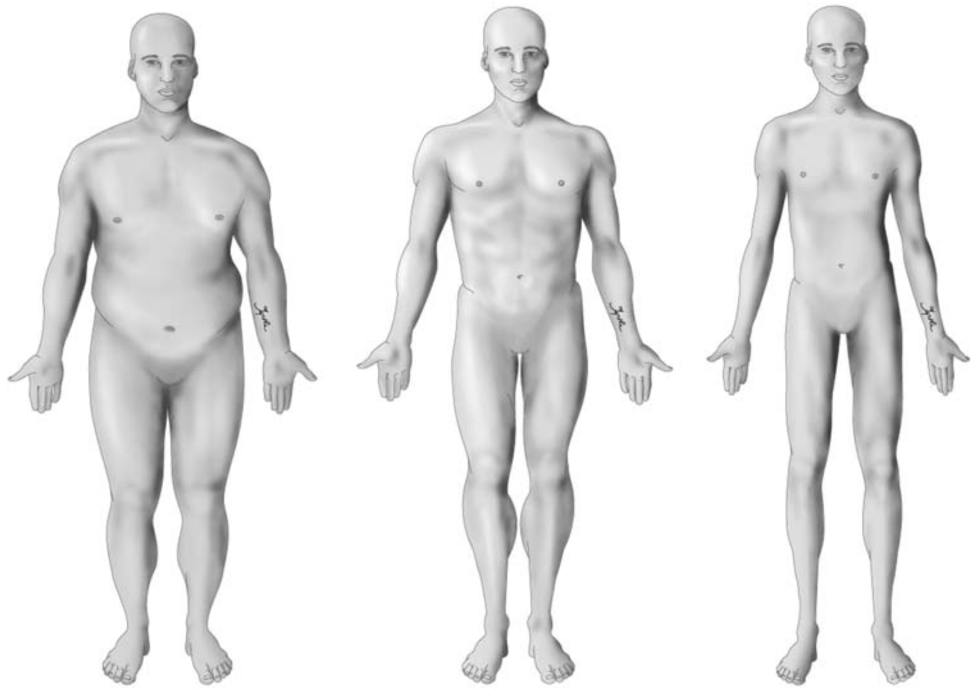


Fig. 1 This diagram depicts the three different morphotypes: endomorph (left), mesomorph (middle), and ectomorph (right).

proximal tibial dimensions. Women, for example, with identical anteroposterior femoral dimensions can have either wide or narrow mediolateral dimensions, indicating other variables such as the patient's specific morphotype may play a role.

Morphotypes have classically been categorized as endomorph, mesomorph, or ectomorph depending on shape and composition of the individual's body [12, 13, 22]. Endomorphs are characterized as having a round body shape with short and tapered extremities, mesomorphs have a muscular and V-shaped body constitution, whereas ectomorphs have a slim and tall morphology with long arms and legs (Fig. 1).

In this study, we therefore wanted to answer the following questions: (1) does gender determine the shape of the knee of European white patients undergoing TKA for osteoarthritis; and (2) does morphotype determine the shape of the knee of European white patients undergoing TKA for osteoarthritis?

Materials and Methods

We prospectively followed all 1000 patients undergoing a primary TKA for end-stage knee disease between April 2003 and June 2007. All patients had a pre- and postoperative computed tomographic (CT) scan of the distal femur and proximal tibia as well as calibrated full-leg radiographs with full pelvic views as part of the prospective protocol. CT scans of the knee were routinely performed for patients undergoing TKA at our institution since 2001 as part of the standard pre- and postoperative radiographic evaluation. Patients who underwent a bilateral TKA were included in the study only once regardless of whether the surgery was performed as a one- or two-stage procedure. Patients with previous ipsilateral unicondylar or patellofemoral arthroplasty were excluded as well as patients of nonwhite race. There were 686 female and 314 male patients. The average age of the male patients was 66 ± 9.5 years (range, 34–84 years) and 68.4 ± 10.5 years (range, 36–89 years) for the female patients. In 64 cases, the quality of the CT scans was insufficient for adequate measurements, and in 43 cases, the quality of the full-leg radiographs did not allow adequate measurements, and these were therefore excluded from the respective analysis. All patients consented to the use of their clinical and radiographic data for the study and the study protocol was approved by the ethical committee of our institution.

In all patients, a CT scan of the distal femur and proximal tibia was taken the day before the operation as well as a calibrated standing full-leg radiograph of both legs, including a full view of the pelvis. All radiographic and CT measurements were digital. CT images were taken with 2-mm slices at the level of the distal femur, and of these slices, the section through the deepest part of the medial epicondylar sulcus was used for the following measurements of the distal femoral geometry: distal femoral width at the level of the epicondyles (AB), distal femoral width at the level of the centre of the posterior condyles (CD), distal femoral width at the level of the trochlea (EF), height of the lateral femoral condyle (CE), and height of the medial femoral condyle (DF) (Fig. 2). One of the coauthors (KC) made all measurements. The epicondylar line was first determined by connecting the most prominent point of the lateral epicondyle (A) with the deepest point of the medial epicondylar sulcus (B), and distance AB was determined as the width between these anatomic points [12]. Next, the most posterior point of the lateral (C) and medial condyle (D) was determined perpendicular to the epicondylar line, and the distance between both (CD) was measured parallel to the epicondylar line. Likewise, the most anterior point of the lateral (E) and medial trochlea (F) was defined perpendicular to the epicondylar line, and the distance between both points was measured parallel to the epicondylar line (EF). The height of the lateral femoral condyle (CE) was measured perpendicular to epicondylar line between the most posterior condylar (C) and anterior trochlear point (E) of the lateral condyle. The height of the medial femoral condyle (DF) was measured perpendicular to the epicondylar line between the most posterior condylar (D) and anterior trochlear point (F) on the medial condyle. The femoral aspect ratio as an indicator of relative femoral width was defined as AB/CE. All patients were ranked according to the height of the lateral condyle (CE) as small (Number 1 to 250), intermediate (Number 251 to 500), or large (Number 501 to 1000).

The preoperative full-leg radiographs were taken with the patients in bipedal stance, the knees in maximal extension, and feet in neutral rotation. These radiographs were calibrated and care was taken to include the whole pelvis to measure the pelvis width, which was defined as the distance between the two anterior superior iliac spinae (Fig. 3). On the same radiographs, we measured the total length of the femur between the most proximal part of the femoral head and the center of the intercondylar notch. The length of the tibia was measured between the most proximal point of the sulcus between the intercondylar eminence and the tibiotalar joint line at the mediolateral center of the ankle. The total leg length was defined as the sum of the length of the femur and tibia. The morphotype of the patient was determined by the following ratio: pelvis width/total leg length.

We defined patients with a high ratio (wide pelvis/short legs) as endomorph, patients with an intermediate ratio as mesomorph, and patients with a low ratio as ectomorph (narrow pelvis/long legs). Patients were classified using the following observed tertiles: the 33% patients with the highest ratio were considered as endomorph, the 33% patients with the lowest ratio as ectomorph, and the middle 33% as mesomorph (Fig. 4).

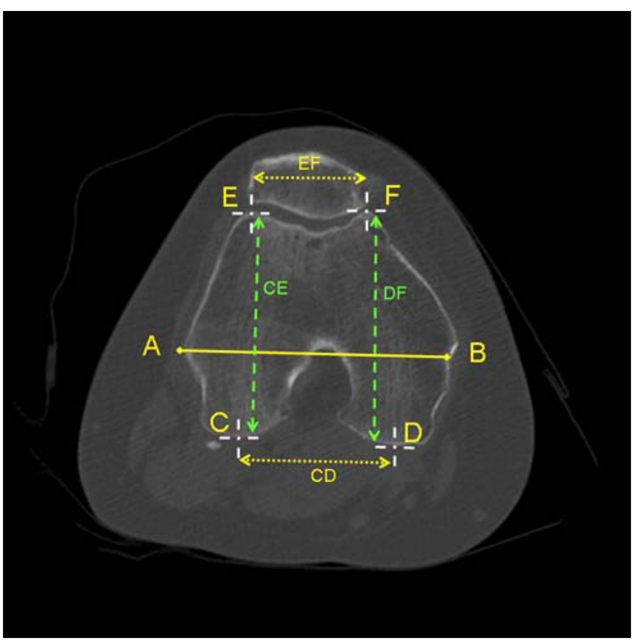


Fig. 2 On this computed tomographic scan, the measurements of the distal femoral geometry are shown.

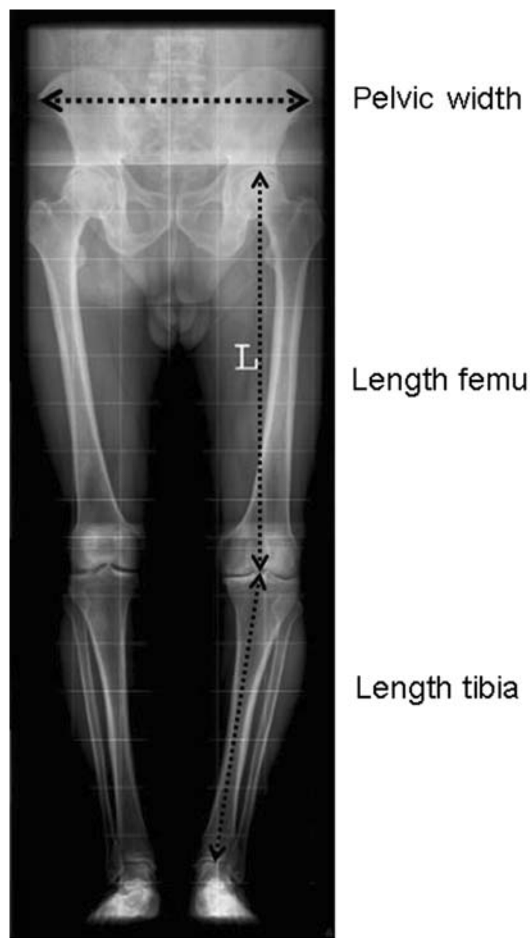


Fig. 3 On this picture, the measurements on the calibrated full leg radiographs are shown to determine the pelvis width/total leg length ratio.

The postoperative CT scans were used to determine the tibial geometry. CT slices were taken every 2 mm, which allowed us to determine the exact tibial resection level for each specific case on which the surgeon had based the tibial sizing. Only the slice just distal to the metal base plate was therefore analyzed. Cement intrusion into the tibial bone was frequently noted as this level (Fig. 5). The following tibial measurements were taken: mediolateral width of the tibial surface (AB), anteroposterior length of the lateral tibial condyle (CD), and anteroposterior length of the medial tibial condyle (EF). We first drew a tangential line along the posterior tibial margin and a second line parallel to this at the level halfway to the most anterior tibial margin. The distance between the intersection points of this second line with the lateral (A) and medial cortex (B) was defined as the tibial width (AB). Next, a line perpendicular to line AB was drawn at 25% and another one at 75% of the tibial width to determine the anteroposterior length of the lateral (CD) and medial (EF) tibial condyle.

All tibias were ranked according to the mediolateral width (AB) as small (Number 1 to 250), intermediate (Number 251 to 500), or large (Number 501 to 1000).

Multiple regression models were used to examine gender and morphotype as predictors for the measured femoral and tibial morphologic dimensions. Likelihood ratio tests were used to compare the performance of various nested models. Chi square tests were used for comparing binary variables, two-sample t tests and Wilcoxon tests for comparing independent variables in two groups (gender). Analysis of variance and Kruskal-Wallis tests were used for comparing variables in three groups (morphotypes). Spearman coefficients were used for determining correlations between geometric dimensions and morphotype. Statistical analysis was performed by the Biostatistical Centre of the School of Public Health of the Catholic University Leuven, using the SAS statistical package version 9.1 (SAS Institute, Cary, NC).

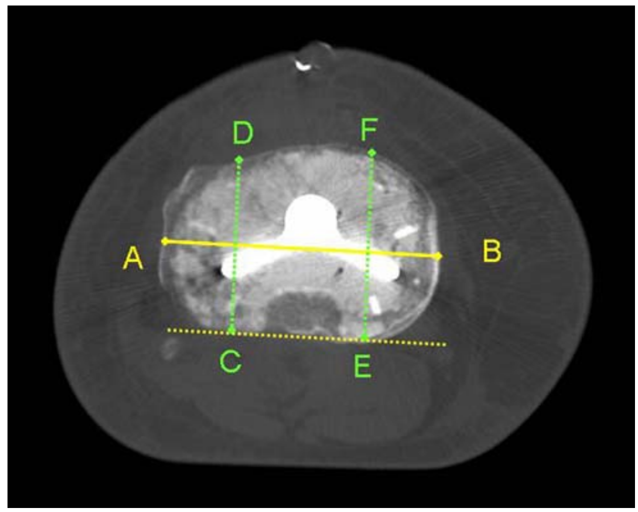
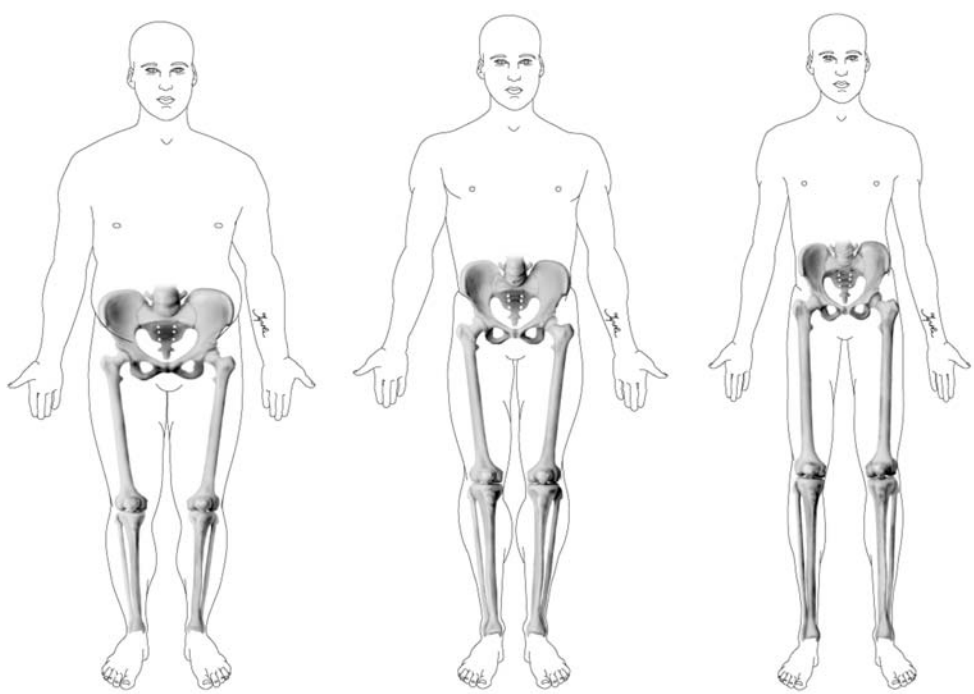


Fig. 5 On this computed tomographic scan, the measurements of the tibial geometry are shown.

Fig. 4 This picture shows how the morphotype characterization was based on the pelvis width/total leg length ratio as endomorph (left), mesomorph (middle), or ectomorph (right).



Results

Female knees were smaller and narrower (both with $p < 0.001$) in distal femoral geometry than male knees (Tables 1, 2). Female tibias were smaller and had greater (also both ($p < 0.001$) mediolateral versus anteroposterior ratios compared with male tibias (Table 2).

Gender predicted ($p < 0.001$) the femoral aspect ratio (AB/CE) with $R^2 = 0.48$, indicating 48% of the variability in distal femoral geometry was explained by gender. Gender more weakly predicted ($p < 0.001$) the tibial aspect ratio (AB/CE) with $R^2 = 0.02$ indicating only 2% of the variability in tibial geometry was explained by the patient's gender.

Patients with short and wide morphotype (endomorph) had, irrespective of gender, wider knees, whereas patients with long and narrow morphotype (ectomorphism) had more narrow ($p < 0.001$) knees (Tables 3, 4). Morphotype predicted ($p < 0.001$) the femoral aspect ratio (AB/CE) with $R^2 = 0.17$ indicating 17% of the variability in distal femoral geometry was explained by the patient's morphotype. Morphotype more weakly predicted ($p < 0.001$) of the tibial aspect ratio (AB/CE) with $R^2 = 0.04$ indicating only 4% of the variability in tibial geometry was explained by the patient's morphotype.

Of the 250 smallest distal femora, 244 (98%) were female, whereas of the 250 largest, 203 (81%) were male. Of the 500 patients with intermediate-sized distal femora, 104 (21%) were male and 396 (79%) were female (Table 1). Of the 250 smallest tibias, 249 (99.6%) were female, whereas of the 250 largest tibias, 236 (94%) were male. Of the 500 patients with intermediate-sized tibiae, 77 (15%) were male and 423 (85%) were female (Table 4).

Knees with smaller distal femora were wider ($p < 0.001$) in mediolateral versus anteroposterior ratios than larger knees both for males and females (Fig. 6). Patients with smaller distal femora (predominantly female) demonstrated large variability between narrow and wide mediolateral dimensions irrespective of gender. The same was true for knees with larger distal femora (predominantly male) (Fig. 6). We observed no differences in mediolateral

Table 2. Data for male and female patients

Variable	Male	Female
Femoral geometry		
AB/CE	1.31 ± 0.06	1.29 ± 0.06*
CD/CE	0.82 ± 0.05	0.80 ± 0.05*
EF/CE	0.60 ± 0.06	0.58 ± 0.05*
AB/DF	1.31 ± 0.06	1.29 ± 0.07*
CD/DF	0.82 ± 0.05	0.80 ± 0.06*
EF/DF	0.60 ± 0.06	0.58 ± 0.05*
Tibial geometry		
AB/CD	1.56 ± 0.08	1.58 ± 0.09*
AB/EF	1.43 ± 0.07	1.45 ± 0.08*
Pelvis width/total leg length	0.35 ± 0.02	0.37 ± 0.02*

Mean ± standard deviation; * significantly different to male.

Table 3. Data with patients stratified according to morphotype

Variable	Endomorph	Mesomorph	Ectomorph
Femoral geometry			
AB/CE	1.31 ± 0.06	1.29 ± 0.06*	1.28 ± 0.06*
CD/CE	0.81 ± 0.06	0.80 ± 0.05*	0.80 ± 0.05*
EF/CE	0.59 ± 0.05	0.59 ± 0.06	0.58 ± 0.05
AB/DF	1.30 ± 0.07	1.29 ± 0.06	1.29 ± 0.06*
CD/DF	0.81 ± 0.06	0.80 ± 0.05	0.81 ± 0.06
EF/DF	0.58 ± 0.06	0.59 ± 0.05	0.59 ± 0.06
Tibial geometry			
AB/CD	1.58 ± 0.09	1.58 ± 0.09	1.56 ± 0.09†
AB/EF	1.45 ± 0.07	1.45 ± 0.07	1.44 ± 0.08
Pelvis width/total leg length	0.39 ± 0.01	0.37 ± 0.01*	0.34 ± 0.01†

* Significantly different to endomorphs, $p < 0.01$; †significantly different to endomorphs and mesomorphs, $p < 0.01$.

Table 1. Data for distal femur geometry with patients stratified according to the height of the lateral condyle (CE) as small (number 1 to 250), intermediate (number 251 to 750), or large (number 751 to 1000)

Variable	Small (1–250)	Intermediate (251–750)	Large (751–1000)
Male-female	6–244 (2%–98%)	104–396 (21%–79%)*	203-47 (81%–19%)†
AB/CE	1.33 ± 0.06	1.28 ± 0.06*	1.27 ± 0.06*
CD/CE	0.83 ± 0.05	0.80 ± 0.05*	0.80 ± 0.05*
EF/CE	0.60 ± 0.06	0.58 ± 0.05*	0.58 ± 0.05*
AB/DF	1.31 ± 0.07	1.29 ± 0.06*	1.29 ± 0.06*
CD/DF	0.82 ± 0.06	0.80 ± 0.06*	0.81 ± 0.06
EF/DF	0.59 ± 0.06	0.59 ± 0.05	0.58 ± 0.06
Pelvis width/total leg length	0.38 ± 0.02	0.36 ± 0.06*	0.31 ± 0.12†

* Significantly different from small femurs, $p < 0.01$; †significantly different from small and intermediate femurs, $p < 0.01$.

Table 4. Data for tibial geometry with patients stratified according to the mediolateral width of the tibia (AB) as small (number 1 to 250), intermediate (number 251 to 750), or large (number 751 to 1000)

Variable	Small (1–250)	Intermediate (251–750)	Large (751–1000)
Male-female	1–249 (0.4%–99.6%)	77–423 (15%–85%)*	236-17 (94%–6%)†
AB/CD	1.57 ± 0.10	1.58 ± 0.08	1.57 ± 0.09
AB/EF	1.44 ± 0.09	1.45 ± 0.07	1.44 ± 0.07
Pelvis width/total leg length	0.37 ± 0.04	0.36 ± 0.06	0.31 ± 0.12†

* Significantly different to small femurs, $p < 0.01$; †significantly different to small and intermediate femurs, $p < 0.01$.

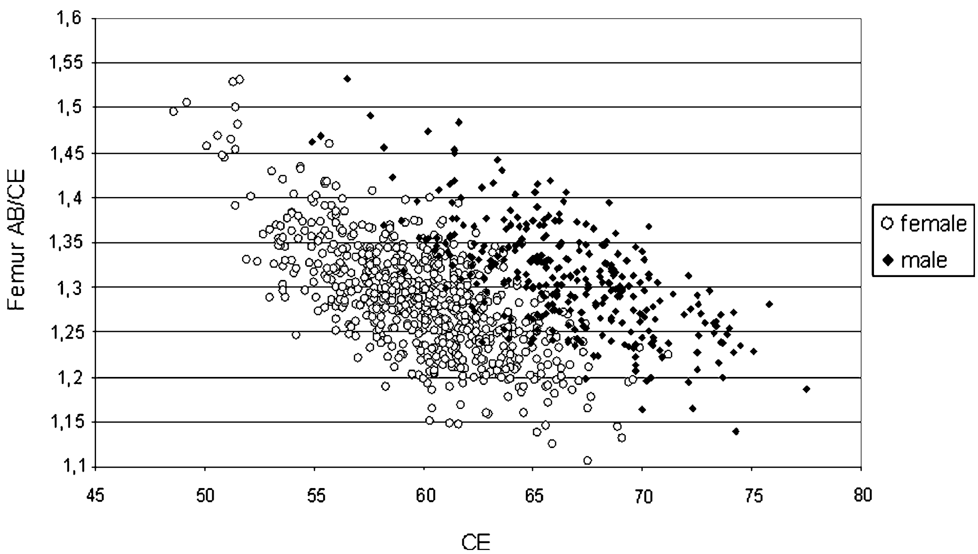


Fig. 6 This graph demonstrates the femoral aspect ratio in function of the femoral size (CE) and gender of the patient.

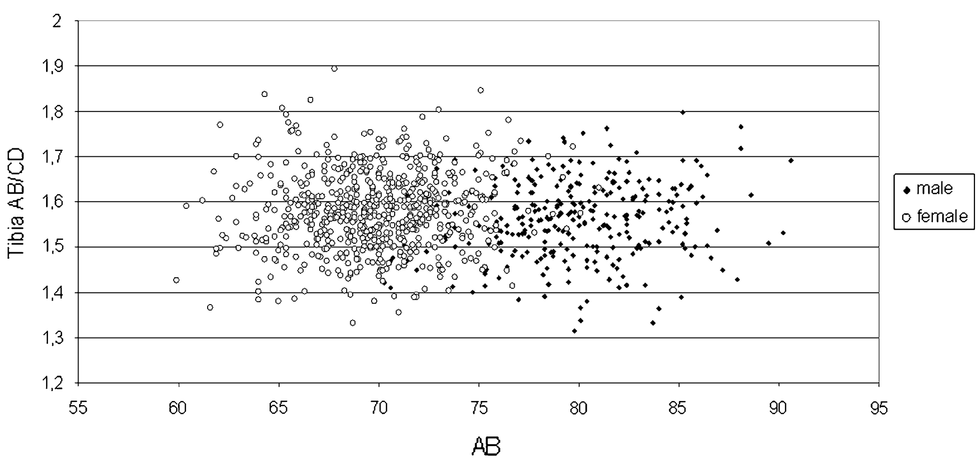


Fig. 7 This graph demonstrates the tibial aspect ratio in function of the tibial size (AB) and gender of the patient.

versus anteroposterior ratios among small, intermediate, or large tibias (Fig. 7).

Discussion

There is today growing evidence that male and female knees are different in geometry [5, 6, 10, 14, 17–19]. For this reason, it seems logical to consider the development and use of gender-specific knee implants that more closely replicate the gender-specific anatomy, thereby optimizing the implant fit to the patient's individual geometry [1, 7–9]. However, even within gender there is high variability in distal femoral and proximal tibial dimensions among patients, which suggests other factors than gender seem to have an influence as well [15]. Also, it is well known that patients undergoing TKA are predominantly female and therefore the need for gender-specific implants may be further questioned [7, 11]. We therefore examined whether gender and morphotype determine the shape of the knee in patients undergoing TKA for osteoarthritis. Our results indicate both factors indeed have a predictive value on the shape of the knee.

Our study has a number of limitations. First, the current literature does not support the hypothesis that sizing discrepancy correlates with any short- or long-term clinically important finding. Although our work determines the effect of gender and morphotype on the actual shape of the knee, it therefore provides no evidence that gender- or morphotype-specific implants could be of any clinical value. Second, our population lacked ethnic diversity and the findings might differ in other populations. Third, the absence of patients with rheumatoid or inflammatory arthritis limits our conclusions to patients with osteoarthritis.

We found female knees had on average more narrow distal femurs compared with male knees. Each mediolateral over anteroposterior femoral ratio that we studied was indeed smaller for female patients compared with male and therefore confirms what other authors have published before [7, 14, 17, 20]. At first sight, this may seem paradoxical because our study has also demonstrated small knees are wider in mediolateral versus anteroposterior femoral ratios compared with larger-sized knees. Because female knees are on average smaller than male knees, one would therefore expect females knees on average to be wider in femoral aspect ratios compared with male knees. The reason this is not the case is the fact that not only gender, but also morphotype plays a role.

Patients with a short and wide morphotype (endomorphs) had, irrespective of gender, greater mediolateral versus anteroposterior ratios and thus wider knees compared with patients with long and narrow morphotypes (ectomorphs), which had a more narrow geometry both for the distal femur and proximal tibia. Our study therefore suggests both morphotype and gender are determinants with respect to the geometry of the distal femur and proximal tibia. For the distal femoral geometry, gender was a stronger predictor in our study than morphotype and contributed 48% to the variability in distal femoral aspect ratio compared with 17% for morphotype. For the proximal tibial geometry, morphotype was the strongest predictor. The influence was, however, less pronounced than for the distal femur, with morphotype only contributing 4% to the variability in the tibial aspect ratio versus 2% by the patient's gender. In other words, although distal femoral geometry seems to be influenced in an important way by gender and morphotype of the patient, this is also true for the proximal tibia but to a much lesser extent.

The fact that morphotype is a predictive variable to the actual shape of the knee is not so surprising. Researchers have recognized the close interrelationship between morphotype and physical characteristics for a long time, which has led to many studies on the influence of morphotype on physical skills and performance [2, 4, 16, 23]. The morphotype concept was initially introduced by Sheldon in the 1940s and later refined by Carter and Heath, who defined the three basic somatotypes (endo-, meso-, and ectomorph) based on the study of thousands photographed bodies of men from front view, side view, and back view [12, 13, 22]. In this theory, the three somatotypes form a basic classification under which any person can be subdivided depending on his skeletal frame and body composition. Although the morphotype concept has received many criticisms in the past for its simplicity and (mis)use by anthropologists and behavioral scientists to correlate certain morphotypes with certain psychologic characteristics, there is much less discussion on its validity with respect to the study of physical characteristics [2, 4, 16, 23]. Our work in a certain way confirms this by demonstrating the correlation of morphotype with the geometric shape of the knee.

Our study also confirms the influence of gender on the shape of the knee and therefore seems to support the theoretical concept of gender-specific implant geometry, at least for the intermediate sizes [1, 6, 14, 18]. Whether such implants lead to improved clinical results is, however, another matter and not yet confirmed [3, 7, 9]. Some recent studies have indeed failed to demonstrate a difference in outcome between male and female patients using standard TKA components. MacDonald et al. evaluated the outcome of a consecutive cohort of 3817 patients after TKA, and the authors could not demonstrate a definitive gender bias in outcome scores [17]. They therefore refuted the hypothesis of inferior clinical outcome for women after TKA when standard components were used, and based on their study, the development of specific knee implants for female patients could not be supported. In another recent paper, Merchant et al. reviewed the orthopaedic literature in an attempt to determine whether women had worse results than men after TKA when traditional gender-neutral components are used [19]. The overall results of the 19 published studies that fulfilled the authors' criteria for inclusion failed to demonstrate worse results for women than for men and in fact just the opposite was true. The results showed women achieved results that were at least as good as or even better than men. These authors therefore concluded the theory that places woman at a disadvantage to men when gender-neutral components are used is not correct. Based on the clinical data available from these studies, the need for gender-specific implants therefore cannot be really supported [17, 19].

Given the absence of clinical data supporting gender-specific implants, it is also interesting to note we found that within gender substantial variability exists in mediolateral versus anteroposterior dimensions and that variability is partly explained by the influence of morphotype. The standard deviations of the geometric data always exceeded the difference in mean values between the groups, sometimes by two- to threefold. This makes it hard to suggest the relatively small differences in the mean values are clinically relevant.

Patients with smaller knees (predominantly female) demonstrated large variability between narrow and wide mediolateral dimensions for any given anteroposterior size irrespective of gender. The same was also true for larger knees (predominantly male). It could therefore make sense to consider variable mediolateral implant dimensions to span this divergence in patient's morphology, even within the same gender. Again, it remains to be seen whether this could lead to a better clinical outcome. Indeed, although our data demonstrate the shape of the knee is determined both by gender and morphotype of the patient, they are not compelling in terms of implant design. In fact, our data illustrate gender-specific implants would not necessarily fit any better than gender-neutral designs. In view of the current clinical data lacking evidence for difference in outcome between men and women using gender-neutral designs, the bias toward more unnecessary expensive designs has until today been justified on a clinical basis. Further clinical evidence is necessary to demonstrate that subtle improvements in fit could result in better knee function.

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